
Optimal Network Reconfiguration and Distributed Generation Placement in Distribution System Using a Hybrid Algorithm

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Abstract: In this paper a method for solving optimal distribution network reconfiguration and optimal placement distributed generation (DG) with the objective of reducing power losses and improving voltage profile with the least amount of time using a combination of various techniques is offered. In the proposed method, first, a meta-heuristic algorithm (MHA) is used to solve the problem of optimal DG placement. The search space for using this technique has been reduced to the optimal scale which is why this technique is accurate and quick. After solving optimal DG placement using the abovementioned technique, a binary particular swarm optimization algorithm (BPSO) is presented for solving the network reconfiguration. In fact, by reducing the search space, the speed of the technique for solving the problem is improved. The proposed technique has been implemented with different scenarios on IEEE 33- and 69-node test systems. The comparison of the results with those of other methods indicates the effectiveness of this technique.

Keywords: Distribution Network Reconfiguration, Distributed Generation, Hybrid Algorithm, Meta-Heuristic Algorithm, Binary Particular Swarm Optimization Algorithm, Power Loss

1. Introduction

Distributed Generation plays an important role in electricity markets and power systems. Installation of DG on distribution feeders can have a significant impact on power system operation and control [1]. DG can be fitted with different strategies in the power network. For example, reducing power losses, cost reduction peak load, improving voltage profile or system reliability, all depend on the location and size of the DG [2]. Since selection of the best locations and sizes of DG units is also a complex combinatorial optimization problem, many methods are proposed in this area in the recent past [3]. Wang and Nehrir [4] proposed an analytical method to determine optimal location to place a DG in distribution system for power loss minimization. Celli *et al.* [5] presented a multi-objective algorithm using GA for siting and sizing of DG in distribution system.

Optimal network reconfiguration is, in fact, the best network configuration among all existing configurations in

the network. Since distribution networks are configured in a radial manner, switches that are normally open or closed are strategic points of the network for reconfiguration. In general, reconfiguration to reduce power losses and eliminate overload or improve voltage profile in the network takes place which with the feeder load change and proper opening and closing of the switches can perform these actions [6]. Distribution network reconfiguration is a problem of complicated multi-objective integer combination optimization. The complexity of the problem arises from the fact that distribution network topology has to be radial and power flow constraints are nonlinear in nature [7]. Merlin and Back [8] proposed a heuristic algorithm to determine the minimum losses configuration. In this algorithm, all network switches are first closed to form a meshed network. The switches are then opened successively to restore radial configuration. Other heuristic algorithms were proposed by Civanlar *et al.* [9]. Artificial intelligence methods have also been applied to distribution network reconfiguration problems extensively, for

example, genetic algorithms [10], neural networks [11], simulated annealing [12], swarm optimization [13], ant colonies [14]. In [3], authors have dealt with network reconfiguration and DG placement simultaneously using Harmony Search Algorithm (HSA) based only on minimization of power losses. In [15] using fireworks optimization algorithm for solving the distribution system network, reconfiguration, together with DG placement, for the problem of power loss minimization and voltage stability enhancement has been done.

The proposed technique combines the BPSO algorithm for solving the optimal network reconfiguration with MHA algorithm for solving the optimal placement of DG. The proposed technique has been validated on two standard IEEE 33- and 69-node test systems, and the simulated results were

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} = P_k - \frac{R_k}{|V_k|^2} \{P_k^2 + (Q_k + Y_k|V_k|^2)^2\} - P_{Lk+1} \quad (1)$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} = Q_k - \frac{X_k}{|V_k|^2} \{P_k^2 + (Q_k + Y_k|V_k|^2)^2\} - Y_{k1}|V_k|^2 - Y_{k2}|V_{k+1}|^2 - Q_{Lk+1} \quad (2)$$

$$|V_{k+1}|^2 = |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2} (P_k^2 + Q_k^2) - 2(R_k P_k + X_k Q_k) = |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2} (P_k^2 + (Q_k + Y_k|V_k|^2)^2) - 2(R_k P_k + X_k (Q_k + Y_k|V_k|^2)) \quad (3)$$

The power loss in the line section connecting nodes k and $k + 1$ may be computed as

$$P_{Loss}(k, k + 1) = R_k * \left(\frac{P_k^2 + Q_k^2}{|V_k|^2} \right) \quad (4)$$

The total power loss of the system is determined by the summation of losses in all the line section, which is given as

$$P_{T,Loss} = \sum_{k=1}^{NL} P_{Loss}(k, k + 1) \quad (5)$$

2.2. Power Loss Using Network Reconfiguration

The power loss of a line section connecting nodes between k and $k + 1$ after reconfiguration of network can be computed as

$$P_{Loss}^{Rec}(k, k + 1) = R_k * \left(\frac{P_k^{Rec^2} + Q_k^{Rec^2}}{|V_k^{Rec}|^2} \right) \quad (6)$$

The total power loss after reconfiguration of the system is determined by the summation of losses in all the line section, which is given as

$$P_{T,Loss}^{Rec} = \sum_{k=1}^{NL} P_{Loss}^{Rec}(k, k + 1) \quad (7)$$

2.3. Objective Function of the Problem

The objective function of the problem is formulated to minimize the power loss reduction in distributed system, which is given by

$$\text{minimize } f(1) = \min. \left(\frac{P_{T,Loss}^{DG}}{P_{T,Loss}} \right) \quad (8)$$

$$\text{minimize } f(2) = \min. \left(\frac{P_{T,Loss}^{Rec}}{f(1)} \right) \quad (9)$$

2.4. Constraints of the Problem

compared with the results of other techniques available [3-15] in the literature to assess the performance and effectiveness of the proposed method.

This paper is organized as follows: Section 2 gives the problem formulation, Section 3 overview of the hybrid algorithm and the proposed method, Section 4 presents results, and Section 5 outlines conclusions.

2. Problem Formulation

2.1. Power Flow Equations

Power flows in a distribution system are computed by the following set of equations [16]:

- 1) Apparent Power flow through any distribution feeder must comply with the thermal capacity of line, that is,

$$|S_k| \leq |S_{k,max}| \quad (10)$$

- 2) Node voltages and line currents limits:

$$V_{k,min} \leq |V_k^{Rec}| \leq V_{k,max} \quad (11)$$

$$V_{k,min} \leq |V_k^{DG}| \leq V_{k,max} \quad (12)$$

$$|I_{k,k+1}^{Rec}| \leq |I_{k,k+1,max}| \quad (13)$$

$$|I_{k,k+1}^{DG}| \leq |I_{k,k+1,max}| \quad (14)$$

- 3) Power conservation limits:

$$P_{Sub} + \sum_{k=1}^{NC} P_{DG,k} = \sum_{k=1}^{NL} P_{Loss}(k, k + 1) + \sum_{k=2}^{Nn} P_{Load,k} \quad (15)$$

- 4) DG capacity limit:

$$P_T^{DG} \leq \frac{P_{Sub}}{2} \quad (16)$$

- 5) DG location limit:

The search space for each DG unit location limited to four nodes candidate:

$$N_C = N_{DG} * 4 \text{ candidate} \quad (17)$$

- 6) The radial constraint is verified by using incidence matrix (A).

$$\det(A) = 0 (\text{not radial})$$

$$\det(A) = 1 \text{ or } -1 (\text{radial system})$$

3. The Proposed Method by Hybrid Algorithm

3.1. Objective Function of the Problem

A hybrid algorithm is an algorithm that combines two or more other algorithms that solve the same problem, either choosing one (depending on the data), or switching between them over the course of the algorithm. This is generally done to combine desired features of each, so that the overall algorithm is better than the individual components. In [17], network reconfiguration and DG placement simultaneously using novel hybrid method of meta-heuristic and heuristic algorithms in order to boost robustness and shorten the computational runtime to achieve network minimum loss configuration in the presence of DGs. In [18], Optimal reconfiguration using a combination of Tabu Search (TS) and Branch Exchange (BE) in order to minimize energy loss.

3.2. MHA for Solving Optimal DG Placement

The stages of the proposed meta-heuristic algorithm for DG placement which does not need much time to be solved consist of the following:

Step 1: Close all tie switches in the network. (Ring network)

Step 2: We find the node that has the least voltage profile and select it as the first candidate for installing DG. Are we considering the initial optimal value of this DG, 1/3 of the active power of the network and we put it in the network. Then, by obtaining power flow in the network, we calculate network loss. Now we limit the next candidate for installing this DG to one to three nodes before the selected node. By installing this DG on these nodes, the node that has the least power loss is the suitable one for installing this DG (Figure 1).

Step 3: For adding another DG to the network, first, turn the network to the normal condition (Radial network). Second, we act as in step 2 by considering the presence of the first DG in the network and calculating power flow with the change that the value of the second DG is 1/3 of the first DG. In the same way we consider the value of the next DG 1/3 of the previous DG. The results of simulation show that the 1/3 estimation is quite optimal. The next DG placements are obtained in the presence of the first DG as in Figure 2.

Step 4: After we have had enough optimal DG placements in the network, we do the reconfiguration in the presence of all the DGs which leads to a quite optimal result. Accordingly, by limiting the search space for finding the optimal placement and estimating the optimal value of the DG there is no need to spend a lot of time for solving the problem and the simulation results show that it is quite optimal.

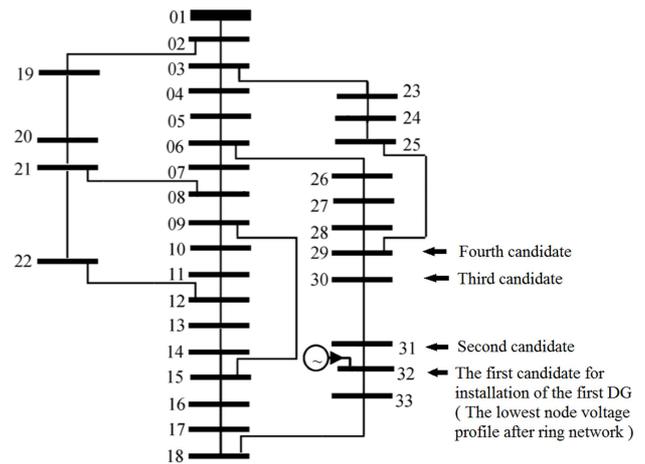


Fig. 1. Optimum location for installation of the first DG.

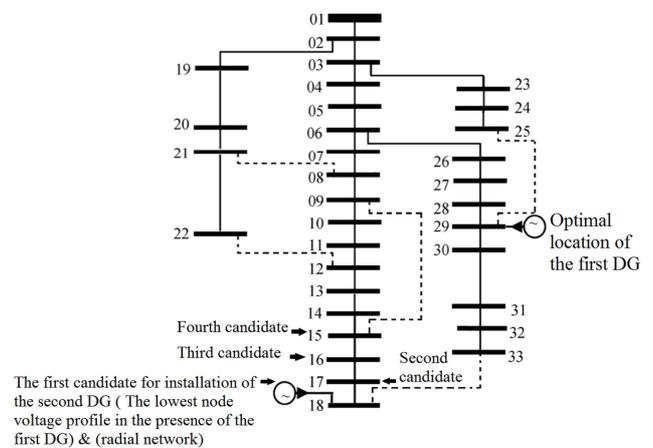


Fig. 2. Optimum location for installation of the next DG.

3.3. BPSO for Solving Network Reconfiguration

The parameters of BPSO algorithm used in the simulation of network are Number of iterations $N_{Max} = 3$, Number of runs $N_{run} = 10$, Inertia weight $W_{max} = 0.9$, $W_{min} = 0.4$, and Acceleration constants $C_{1,2} = 2$. The search space was optimally reduced which leads to high accuracy and fast performance of this technique. Indeed, by removing the switches that are not effective in solving optimization problem the performance of this technique improves. By using the 33-node system the way to find the optimal search space is shown.

Step 1: By closing all tie switches, the network will become multi loop. Now to specify any loop in the network, one should note that each tie switch must belong to a loop. In Figure 3, each loop is shown with different geometric shapes.

Step 2: Removing the branches that do not belong to any of the loops. In Figures 3, they are not shown with any geometric shapes.

Step 3: Removing the branch of the loops which does not share with other loops.

a) If a desired branch has more than three switches, it will be removed.

b) If a branch is divided into two parts by a tie switch, the

part that has the minimum number of switches will be removed. If the tie switch does not share with another loop, it will be removed itself.

Step 4: After the network has been simplified we go to step 2 and do the simplification again bearing in mind that in repeating the process no tie switch will be removed (Figure 4).

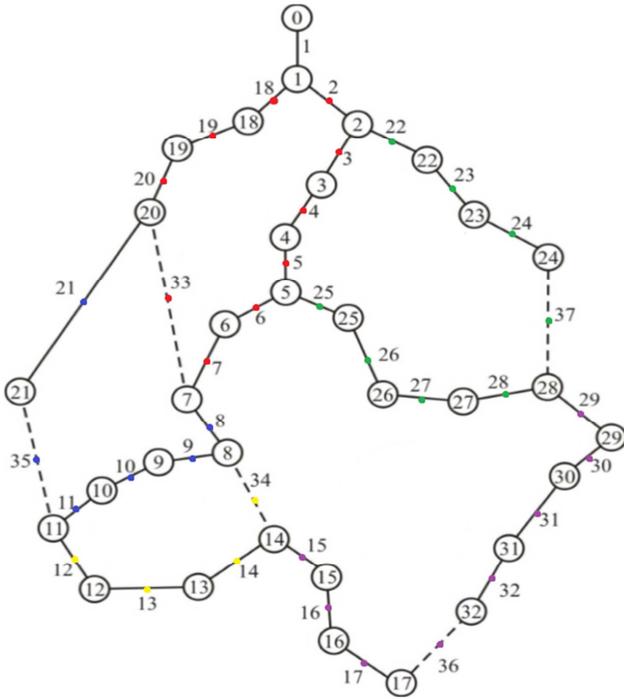


Fig. 3. Search space of the 33-node system.

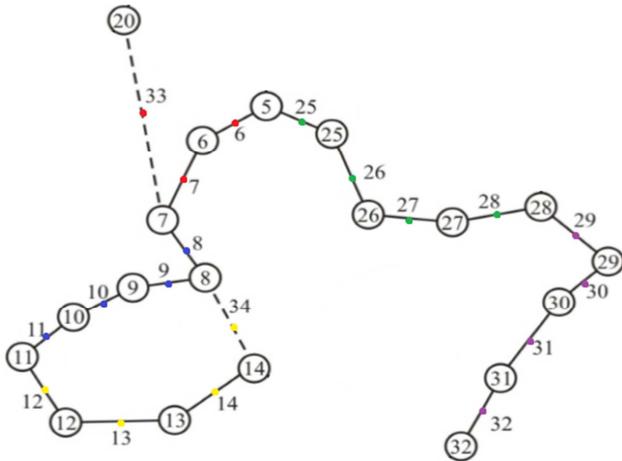


Fig. 4. Optimum search space of the 33-node system.

Therefore, with the proposed method, the search space in the 33-node system is reduced from 37 switches to 19 switches and it is reduced in the 69-node system from 73 switches to 19 switches. So the optimal search space to find the suitable switches for opening or closing in the network is as follows with each row of the matrix representing each loop in the network:

$$SS_{33\text{-node}} = \begin{bmatrix} 6 & 7 & 33 & 0 \\ 8 & 9 & 10 & 11 \\ 12 & 13 & 14 & 34 \\ 25 & 26 & 27 & 28 \\ 29 & 30 & 31 & 32 \end{bmatrix}$$

$$SS_{69\text{-node}} = \begin{bmatrix} 11 & 12 & 0 & 0 & 0 & 0 & 0 \\ 9 & 10 & 69 & 0 & 0 & 0 & 0 \\ 52 & 53 & 54 & 55 & 56 & 57 & 58 \\ 59 & 60 & 61 & 62 & 63 & 64 & 0 \\ 70 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

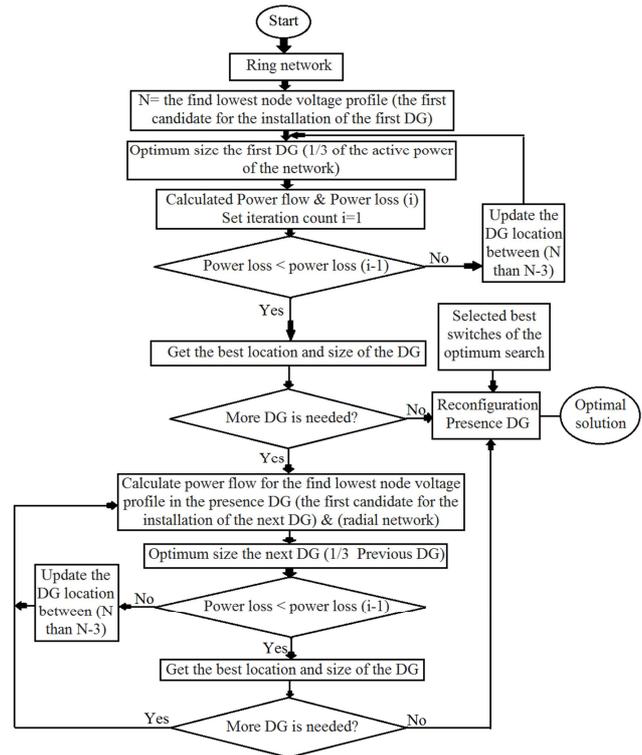


Fig. 5. Flow chart of the proposed technique HBA.

4. Simulation Results

In order to demonstrate the effectiveness of the proposed technique using HBA, it is applied to two test systems consisting of 33 and 69 node. In the simulation of network, eight scenarios are considered to analyze the superiority of the proposed technique. The results simulated are compared with the results of other techniques such as FWA [15] and HSA [3] and GA [3] to assess the performance and effectiveness of the proposed technique.

- Scenario I: The system is without reconfiguration and DG (Base case);
- Scenario II: The system is with reconfiguration and without DG unit;
- Scenario III: The system is without reconfiguration and with installation of the first DG unit;
- Scenario IV: The system is with reconfiguration and installation of the first DG unit;
- Scenario V: The system is without reconfiguration and

with installation of the two DG units;

Scenario VI: The system is with reconfiguration and installation of the two DG units;

Scenario VII: The system is without reconfiguration and with installation of the three DG units;

Scenario VIII: The system is with reconfiguration and installation of the three DG units (Optimal solution).

All scenarios are programmed in MATLAB, and simulations are carried on a computer with Pentium IV, 1.8 GHz, 2 GB RAM.

4.1. 33-Node Test System

The line, load and tie line data of this test system are taken from [19]. The normally closed sectionalize switches are 1–32 and the open tie switches are 33–37. The single line diagram of 33-node system with the loops formed corresponding to each tie switch is shown in Fig. 1. The total real and reactive power loads of the system are 3715 KW and 2300 KVAR, respectively.

The performance of the proposed method at nominal load level is presented in Table 1. The total power loss (kW) at nominal load condition is reduced from 202.67 to 64.96 in

scenario VIII respectively. In order to illustrate the performance of the proposed technique, the performance of HBA is compared with the results of FWA [15], HSA [3] and GA [3] available in the literature and is presented in Table 2.

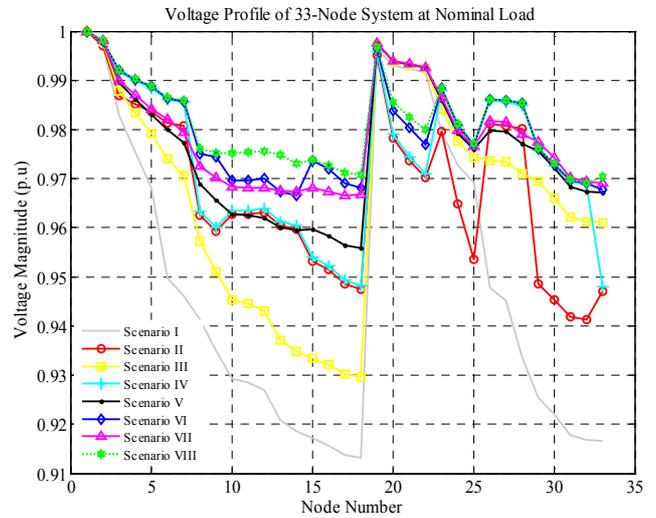


Fig. 6. Voltage profile of 33-node system.

Table 1. Results of 33-node system.

Scenario	Switches Opened	Power Loss (KW)	Min Voltage (p.u)	Size of DG in MW (Location)	CPU Time (s)
Scenario I	33, 34, 35, 36, 37	202.67	0.9131	-	-
Scenario II	07, 09, 14, 28, 32	139.98	0.9412	-	1.969
Scenario III	33, 34, 35, 36, 37	120.63	0.9295	1.23830 (29)	0.003
Scenario IV	07, 09, 14, 28, 32	89.81	0.9479	1.23830 (29)	2.532
Scenario V	33, 34, 35, 36, 37	93.5	0.9558	1.23830 (29) 0.41278 (15)	0.01
Scenario VI	07, 09, 13, 28, 32	69.64	0.9662	1.23830 (29) 0.41278 (15)	3.043
Scenario VII	33, 34, 35, 36, 37	88.78	0.9666	1.23830 (29) 0.41278 (15) 0.13759 (18)	0.02
Scenario VIII	07, 09, 13, 28, 32	64.97	0.9691	1.23830 (29) 0.41278 (15) 0.13759 (18)	3.552

Table 2. Comparison of simulation results of 33-node system.

Method	Item	Scenario VIII Optimal solution	Scenario VII Only DG Installation
Proposed Method (HBA)	Switches opened	07, 09, 13, 28, 32	33, 34, 35, 36, 37
	Power Loss (KW)	64.97	88.78
	Power Loss %	67.94	56.19
	Min Voltage (p.u)	0.9691	0.9666
	Total DG Size (MW)	1.7887	1.7887
HSA Ref [3]	Switches opened	07, 14, 10, 32, 28	33, 34, 35, 36, 37
	Power Loss (KW)	73.05	96.76
	Power Loss %	63.95	52.26
	Min Voltage (p.u)	0.9700	0.9670
	Total DG Size (MW)	1.6684	1.7256
GA Ref [3]	Switches opened	07, 34, 10, 32, 28	33, 34, 35, 36, 37
	Power Loss (KW)	75.13	100.1
	Power Loss %	62.92	50.60
	Min Voltage (p.u)	0.9766	0.9605
	Total DG Size (MW)	1.9633	1.6044
FWA Ref [15]	Switches opened	07, 14, 11, 32, 28	33, 34, 35, 36, 37
	Power Loss (KW)	67.11	88.68
	Power Loss %	66.89	56.24
	Min Voltage (p.u)	0.9713	0.9680
	Total DG Size (MW)	1.6841	1.7937

4.2. 69-Node Test System

This is a 69-node large scale radial distribution system with 68 sectionalizing and five tie switches. Configuration, line, load, and tie line data are taken from [20]. Total system loads for base configuration are 3802.19 KW and 2694,06 KVAR. The sectionalizing switches are labeled from 1 to 68 and tie

switches from 69 to 73, respectively.

Similar to 33 node test system, this test system is also simulated for eight scenarios at one load level and the results are presented in Table 3. The total power loss (KW) at nominal load condition is reduced from 224.96 to 38.36 in scenario VIII respectively.

Table 3. Results of 69-node system.

	Switches Opened	Power Loss (KW)	Min Voltage (p.u)	Size of DG in MW (Location)	CPU Time (s)
Scenario I	69, 70, 71, 72, 73	224.97	0.9091	-	-
Scenario II	12, 58, 61, 69, 70	98.79	0.9494	-	2.556
Scenario III	69, 70, 71, 72, 73	96.58	0.9578	1.2673 (61)	0.001
Scenario IV	12, 55, 64, 69, 70	50.54	0.967	1.2673 (61)	3.488
Scenario V	69, 70, 71, 72, 73	83.95	0.9672	1.2673 (61) 0.42243 (64)	0.008
Scenario VI	12, 56, 61, 69, 70	39.49	0.9776	1.2673 (61) 0.42243 (64)	4.372
Scenario VII	69, 70, 71, 72, 73	78.1	0.9743	1.2673 (61) 0.14081 (24)	0.01
Scenario VIII	12, 57, 61, 69, 70	38.36	0.9777	1.2673 (61) 0.42243 (64) 0.14081 (24)	5.26

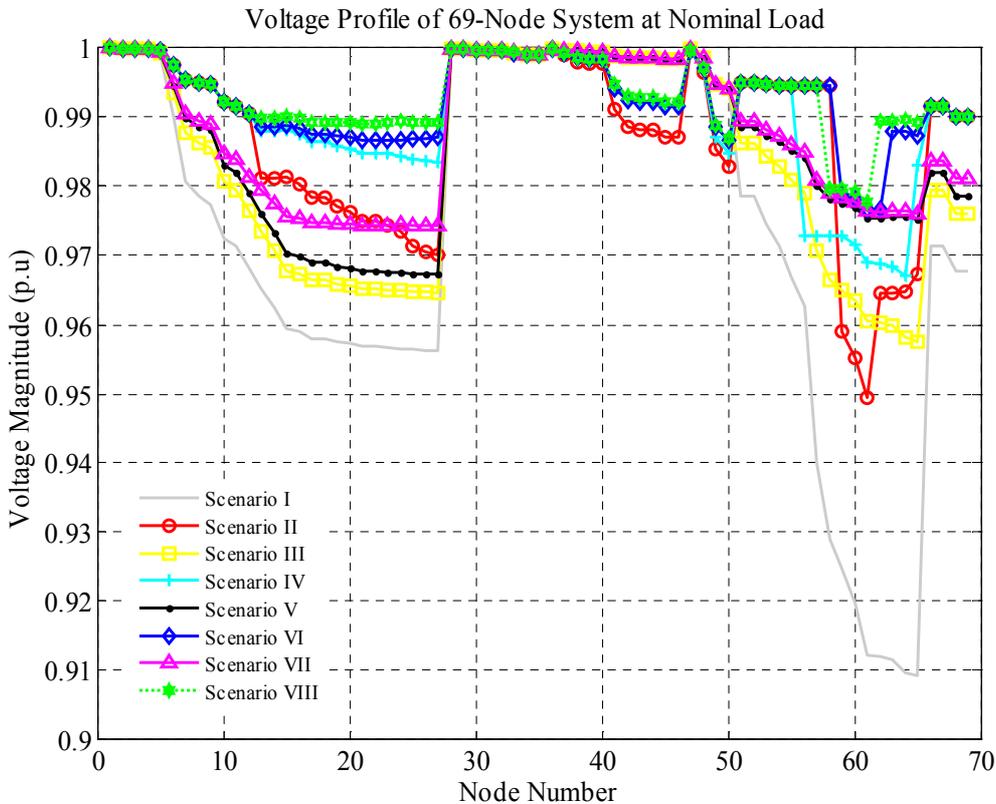


Fig. 7. Voltage profile of 69-node system.

The performance of HBA on 69-node system is also compared with the results of FWA and HAS and GA methods similar to 33-node system, and the results are presented in Table 4.

Table 4. Comparison of simulation results of 69-node system.

Method	Item	Scenario VIII Optimal solution	Scenario VII Only DG installation
Proposed Method (HBA)	Switches opened	12, 57, 61, 69, 70	69, 70, 71, 72, 73
	Power Loss (KW)	38.36	78.10
	Power Loss %	82.94	65.28
	Min Voltage (p.u)	0.9777	0.9679
	Total DG Size (MW)	1.8305	1.8305
HSA Ref [3]	Switches opened	69, 17, 13, 58, 61	69, 70, 71, 72, 73
	Power Loss (KW)	40.03	86.77
	Power Loss %	82.08	61.43
	Min Voltage (p.u)	0.9736	0.9677
	Total DG Size (MW)	1.8718	1.7732
GA Ref [3]	Switches opened	10, 15, 45, 55, 62	69, 70, 71, 72, 73
	Power Loss (KW)	46.20	88.5
	Power Loss %	73.38	60.66
	Min Voltage (p.u)	0.9727	0.9687
	Total DG Size (MW)	2.0292	1.9471
FWA Ref [15]	Switches opened	69, 70, 13, 55, 63	69, 70, 71, 72, 73
	Power Loss (KW)	39.25	77.85
	Power Loss %	82.55	65.39
	Min Voltage (p.u)	0.9796	0.9740
	Total DG Size (MW)	1.8182	1.8329

5. Conclusion

In this paper a hybrid algorithm for solving optimal distribution network reconfiguration and optimal DG placement with the objective of reducing power loss and improving voltage profile was presented. The first algorithm for solving optimal DG placement is to use a simple meta-heuristic algorithm (MHA) which estimates optimal places for installing DG and their value. The second algorithm for solving reconfiguration is a quick binary particle swarm optimization (BPSO) algorithm. The results obtained clearly

indicate that scenario VIII (DG installation with network reconfiguration) is found to be more effective in minimizing the power loss compared to the other scenarios considered. To show the efficiency of the proposed algorithm tested it on two 33- and 69-node systems. The results show the better performance of this method compared to genetic algorithm (GA), harmony search algorithm (HAS), and fireworks algorithm (FWA). Considering the simplicity and quick performance of this proposed algorithm, one can use it in intelligent networks with total load of less than 10 megavolt ampere and with any number of nodes in real time.

Nomenclature

P_k	Real power flowing out of node k .
Q_k	Reactive power flowing out of node k .
P_k^{Rec}	Real power flowing out of node k after reconfiguration.
Q_k^{Rec}	Reactive power flowing out of node k after reconfiguration.
P_{Lk+1}	Real load power at node $k + 1$.
Q_{Lk+1}	Reactive load power at node $k + 1$.
P_{Sub}	Active power supplied by the substation.
$P_{Load,k}$	Real power load at node k .
$P_{DG,k}$	Real power supplied by DG at node k .
S_k	Apparent power flowing in the line section between nodes k and $k + 1$.
$S_{k,max}$	Maximum power flow capacity limit of line section between nodes k and $k + 1$.
N_L	Total number of lines sections in the system.
N_n	Total number of nodes in the system.
N_C	Number of candidate nodes for DG installation.
N_{DG}	Number of DG unit in the system.
A	Node incidence matrix.
$I_{k,k+1}^{Rec}$	Current in line section between nodes k and $k + 1$ after reconfiguration.
$I_{k,k+1}^{DG}$	Current in line section between nodes k and $k + 1$ after DG installation.
$I_{k,k+1,max}$	Maximum current limit of line section between nodes k and $k + 1$.
R_k	Resistance of the line section between nodes k and $k + 1$.

X_k	Reactance of the line section between nodes k and $k + 1$.
$P_{Loss}(k, k + 1)$	Loss in the line section connecting nodes k and $k + 1$.
$P_{T, Loss}$	Total power loss of the feeder.
$P_{T, Loss}^{Rec}$	Total power loss of the feeder after reconfiguration
$P_{T, Loss}^{DG}$	Total power loss of the feeder with DG.
V_k	Voltage at node k .
V_k^{Rec}	Voltage at node k after reconfiguration.
V_k^{DG}	Voltage at node k after DG installation.
$V_{k max}$	Maximum node voltage at node k .
$V_{k min}$	Minimum node voltage at node k .
Y_k	Shunt admittance at any node k .
P_T^{DG}	Total real power of the DG units.
SS_{Nn}	Search space of the test system.

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